Analysis of Dynamically Driven, Single-crystal Experiments

Irene J. Beyerlein, Francis L. Addessio, Zhiqiang Wang, T-3; George T. Gray, Ellen K. Cerreta, Fang Cao, MST-8

Experiments are being conducted in the Materials Science and Technology (MST) Division to investigate the response of single crystals of copper to impact-loading scenarios. For this purpose, plate impact experiments using a 2.184-mm flyer plate and a 2.261-mm target plate are being considered. Impact velocities of 271 m/s and 518 m/s have been used in the current studies. A target plate that was composed of a bicrystal was employed in the initial experiments. That is, half of the target contained a single crystal that had an orientation of [100], and the other half had an orientation of [011]. A representation of the bicrystal target is provided in Fig. 1. Future targets will contain only a single crystal. In addition to obtaining the particle velocity history on the back surface of the target, postmortem microscopy was performed to quantify the deformation mechanisms within the target material. Phenomena that include substructure evolution, deformation twinning, and damage can be identified in this manner.

Both theoretical and computational support for this experimental investigation are being pursued within the Theoretical Division. The intent is to develop a next-generation, high-rate constitutive model for materials that are of interest to the DOE community. A multilength scale approach is being employed for this support. That is, dislocation dynamics (DD) simulations are being used to develop single-crystal hardening laws applicable to a wide range of strain rates. Of interest is the transition from thermal activation to the dislocation drag regime ($\sim 10^4$-10^7/s). The single-crystal models that result from the DD investigation are being implemented into a plate impact analysis, which uses a continuum mechanics model for the flyer plate and the single-crystal model for the target. A simulation of the plate impact experiments for a target material that is a single crystal of copper oriented in the [100] direction is provided in Fig. 2. The propagation of the stress wave into both the flyer ($0. < x < 0.2184$ cm) and the target (0.2184 cm $< x < 0.4445$ cm) is shown in Fig. 2 at four different times. The evolution of both the elastic precursor and the plastic waves may be seen from the simulation. The single-crystal model that was used in the analysis has its basis in the thermal activation regime and introduces a threshold stress characterized for Cu in this regime, which is relatively rate insensitive. The large spike close to the wave front in the single-crystal material (i.e., the target) is a result of large values of resolved shear stresses several times greater than the critical resolved shear stress provided in the model—their ratio is raised to a large power in the model. It is anticipated that a more realistic wave profile will result if the dislocation drag regime with a higher rate sensitivity is included in the model.

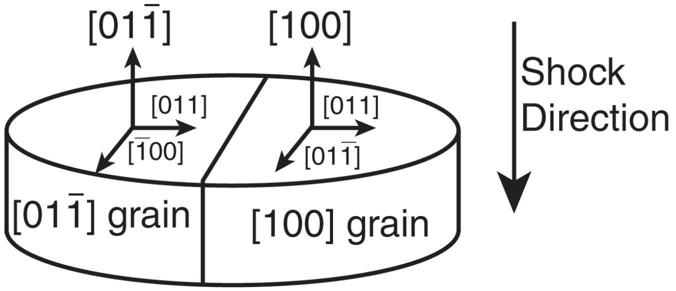

Fig. 1. Diagram of the bicrystal target plate.

For further information contact Francis L. Addessio at addessio@lanl.gov.

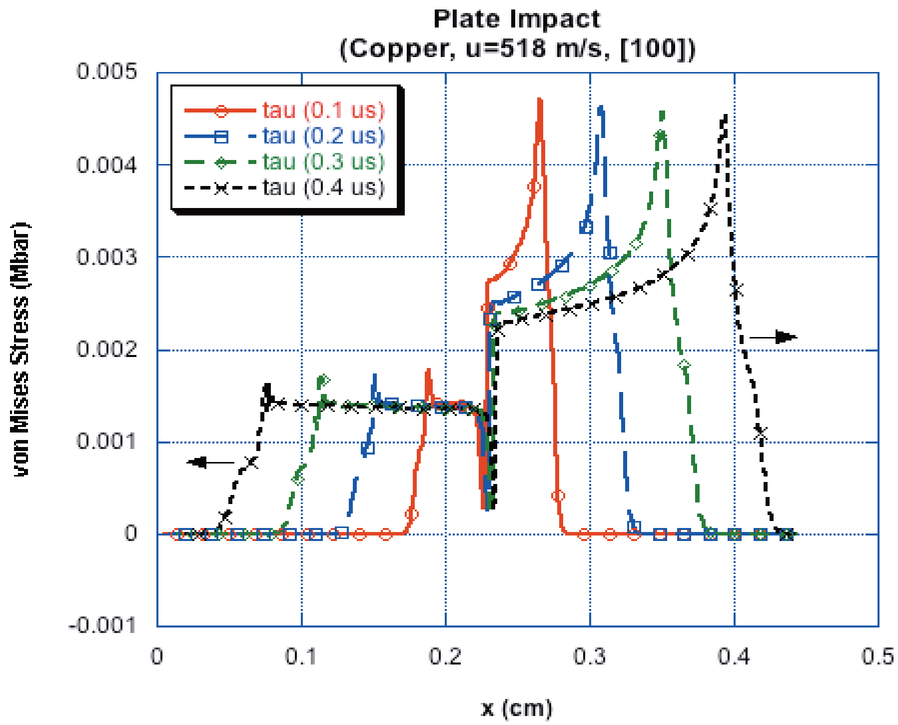

Fig. 2. Single-crystal analysis of a [100] oriented copper crystal at an impact velocity of 518 m/s.

Funding Acknowledgments
DOE, NNSA, Advanced Simulation and Computing Program